Interactive Simulation To Explore Urban Distribution Schemes

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Abstract
The goal of building a shared vision about city logistics is often obstructed by the diversity of its actors (authorities, carriers, shippers, etc.). As an example, urban deliveries are sometimes not taken into account in the urban planning of cities or are simply misunderstood. This reality highlights the need for accessible and straightforward decision support tools in this field. In this work an interactive simulation is proposed as a playful tool to disseminate theoretical results from academia and lessons learned towards non-experts, who can easily interact with a model. The proposed interactive simulator aims at helping actors to broadly share and enlarge their perspective about a specific problem. That is, identifying the different objectives and constraints of other actors and converging towards a collective solution to the problem at hand. A trial was performed with 28 participants that explored and compared two different distribution schemes using interactive simulation. Positive feedback from the participants shows promising perspectives for this type of tool.
Keywords: city logistics; interactive simulation; decision support; multimodality

1. Introduction

The challenges for the mobility of goods and passengers are getting bigger as cities face greater constraints. In 2050, urban population is expected to represent 80% of the total population in Europe (United Nations, 2014). At the same time, in regards to this growing need from the population, the European Commission targets to reduce emissions related to transport to more than 60% of 1990 levels by 2050 (European Commission, 2011). Aside from switching to low-carbon energy, city logistics experts point out the "poor and inappropriate" urban logistics service in large European cities (Dablanc, 2007). Initiatives, such as the "Chappelle International logistic hub" in Paris, show that cities are considering more urban logistics issues in their urban planning. However, there is still room for improvement: the first version of the "Métropole du Grand Paris" urbanization plan (administrative structure for cooperation covering the City of Paris and its nearest suburbs departments) did not consider freight (Debrie and Heitz, 2017). Benefits of raising awareness about city logistics seem obvious: planners are beginning to take into account urban logistics constraints; and voters are understanding the benefits of an efficient transportation system for freight. Although the non-expert public has a growing interest in urban logistics, there is still a significant knowledge gap between them (inhabitants, city planners) and the research community. As a result, non-experts are not always aware of the research contributions. For example, when implementing access regulation based on vehicle size, cities do not expect to see an increase in the number of vehicles. This relationship between vehicle size (i.e. capacity) and number of vehicles for a fixed demand has been largely explored in research related to vehicle routing problems. Interactive simulation could be used to disseminate this type of results in an accessible manner.

To the best knowledge of the authors, there are no interactive tools to engage non-expert public with the constraints of city logistics. It seems important to establish a formal distinction between interactive simulation and Decision Support Systems "DSS" (Comi and Rosati, 2015; Grzybowska and Barceló, 2012; Perboli et al., 2015). DSS has an operational objective (Gabriel and Laporte, 1997), whereas interactive simulation has a teaching objective (Vogel et al., 2006).

Studies show that learners have a preference for interactive simulations compared to traditional teaching methods and cognitive gain can be higher (Vogel et al., 2006). Moreover, it has been shown that interactive simulation can be an efficient way to tackle difficult problems. For example, the Human-based computation game "phylo" is able to leverage the human capacity to solve NP-complete pattern-matching problems (Kawrykow et al., 2012) for comparative genomics. In addition, in the context of transportation, humans are able to propose reasonably good solutions without computer assistance to the "Traveling Salesman Problem" for small instances (Best, 2005).

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In this paper, an interactive simulator has been developed to raise awareness about city logistics towards non-experts. The simulator is accessed through an interface allowing users to modify certain parameters of an urban logistics system and quickly see the impact of their choices. The main objective of this research is to assess if interactivity allows the users to deeply understand the model – by discovering its limits – and therefore the problem it represents.

This paper presents an application case that performs a comparison of an emerging and the traditional distribution scheme for urban distribution. The idea is to use interactive simulation in order to help non-experts to explore and understand these models that might seem trivial to researchers in urban freight, but that are often unknown to inhabitants. To this end, the distribution schemes are model and simulated. The relevance of the tool is discussed after a trial on a group of 28 people.

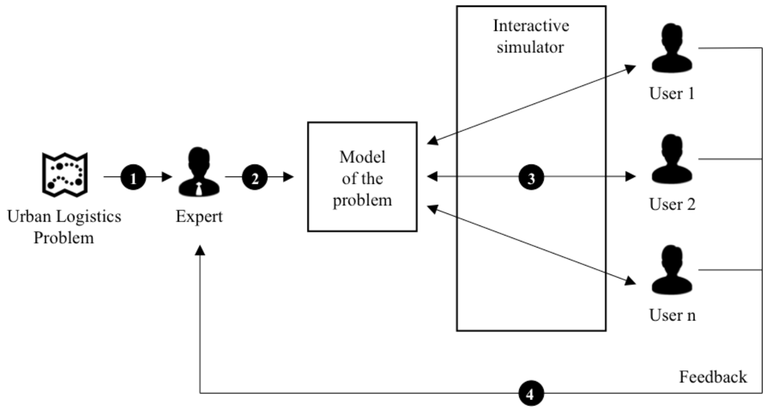

Fig. 1. Overview of the interactive simulator

2. Method

2.1. Use of the interactive simulator

The proposed interactive simulator can be used following four main steps as shown in Fig. 1. In the first step, an urban logistic problem is identified by the expert. In the second step, the expert develops one or several models to represent the problem. In the third step, the interactive simulator acts as an interface between the model(s) and the users. This is the interactive part of the process where users are able to easily change parameters to explore a model, test hypothesis and get familiar with the problem. The fourth and final step consists in collecting feedback from users. The comprehension of users is assessed via a survey.

2.2. Use case

In this paper, interactive simulation is used to compare two distribution schemes for express deliveries of 200 points in the city of Paris. The interactive simulator allows users to quickly test numerous combinations of the parameters. First, the interaction with the simulation aims at teaching the relationship between parameters (e.g. capacity vs. number of vehicles). Secondly, the interactivity puts the user in a better position to criticize the model. As users explore the model, they also understand its limitations (missing parameters, wrong hypothesis, etc.). In other words, the user starts to have a better understanding of the problem as it appears in real life.

The first scheme is a traditional parcel delivery operation (cf. Fig. 2 left). Vans leave a depot in the city center to the assigned points of delivery. The second scheme is multi-modal (cf. Fig. 2 right), one truck (capacity of 200 deliveries) leaves the depot and stops several times in the city. At each stop, parcels are transshipped to bicycle couriers performing the last mile. From an optimization perspective, the first scheme is a vehicle routing problem. And the second scheme can be seen as a Two-echelon Vehicle Routing Problem (Crainic et al., 2010; Drexl and Schneider, 2015; Gonzalez-feliu et al., 2008).

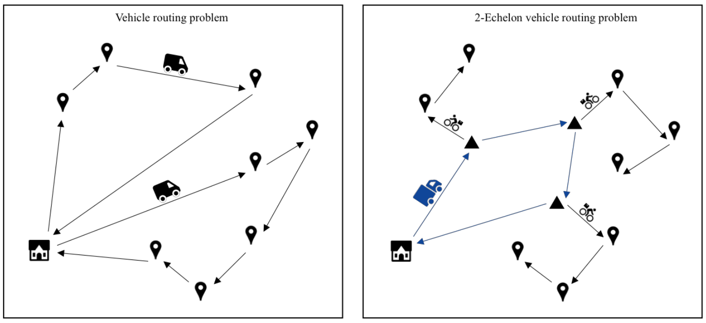

Fig. 2. Models implemented in the interactive simulator

The optimization was carried out using Gurobi 7.5 (MIP solver) and scikit-learn (Python machine learning package), all within a Python 3.5 environment. The distance between the points has been considered as Euclidian. The optimization computes the routing of the vehicles, where the objective is minimizing the total distance traveled. Only one parameter can change the routing of the vehicle: the capacity of the vans or the bikes. All the other parameters have no influence on the optimization results. For example, the fuel consumption or the cost of a vehicle will have no impact on the routing solution. Indeed, the objective is to minimize the total distance. It does not consider the minimization of the operational cost. The KPI (presented in Section 2.3) are computed from the routing solution and the parameters (presented in Section 2.5).

In order to ensure a good level of responsiveness, the interactive simulator contains a database with the resulting routing solutions for all the possible combinations of input parameters. Actually, every possible routing solution is obtained by only changing the vehicle capacity (i.e. van capacity for the VRP and bike capacity for 2EVRP). Then, the KPI are computed from the routing solutions depending on the parameters chosen by the user.

As shown in Fig. 2, the depot and the delivery points are the same for both distribution schemes. It is the actual location of a depot from the French company La Poste. The delivery points are random points in the city of Paris.

2.3. Key Performance Indicators

Three Key Performances Indicators are computed in the interactive simulation model in order to compare the two solutions on the grounds of economic, operational and environmental performance.

- The first KPI is the total cost of delivering 200 points.
- The second KPI is the average time of the delivery tours. This represents the lead-time performance of the distribution, as the tour is shorter (or faster), it is possible to deliver more during peak hours. For example, if all the customers want to receive their deliveries after work hours (between 6pm to 8pm).
- The third KPI aims at representing the environmental performance by estimating the quantity of fine particles generated by the distribution.

The different KPI are used to represent the different interests of the stakeholders.

2.4. Stakeholders

City logistics involve multiple stakeholders, their different interests as described in (Abel et al., 2006) illustrates well the complexity of the system. The shipper aims at minimizing overall cost while meeting the needs of the client. The carrier is also looking for low cost, but additionally wants high-quality transportation operations to satisfy both the shipper and the client. The client desires to be delivered on time and on a short notice. The city wants to be attractive for inhabitants by minimizing negative externalities while having efficient transport operations.

2.5. Parameters

The simulator is initially set up with the parameters presented in Table 1 and Table 2. These estimations are based on information about the city of Paris.

Table 1. Parameters for the Vehicle Routing Problem (Version HBEFA 3.3 2017 – Handbook Emission Factors for Road Transport; Korzhenevych et al., 2014)

Van driver cost: 83 €/driver	Van climate change cost: 2.80 cents €/km
Van cost: 40 €/vehicle	Van air pollution cost: 1.10 cents €/km
Van fuel consumption: 7 L/100 km	Van capacity: 80 deliveries
Van PM emission: 0.049 g/km	Van drop-off duration: 5 min
Van speed: 30 km/h	

Table 2. Parameters for the MDVRP (Version HBEFA 3.3 2017 – Handbook Emission Factors for Road Transport; Korzhenevych et al., 2014)

Truck driver cost: 83 €/driver	Truck climate change cost: 2.80 cents €/km
Truck cost: 50 €/vehicle	Truck air pollution cost: 1.70 cents €/km
Truck fuel consumption: 25 L/100 km	Truck drop-off duration: 5 min
Truck PM emission: 0.057 g/km	Bike drop-off duration: 5 min
Truck speed: 30 km/h	Bike speed: 20 km/h
Truck capacity: 200 deliveries	Bike cost: 5 €/delivery

2.6. Interactivity

Interaction with the model is made possible thanks to the use of the python module "ipwidget" within jupyter notebooks. The module allows to easily creating sliders and buttons. In this case, the user is able to change the simulation parameters (cf. Fig. 3) and directly display the KPIs (cf. Fig. 4).

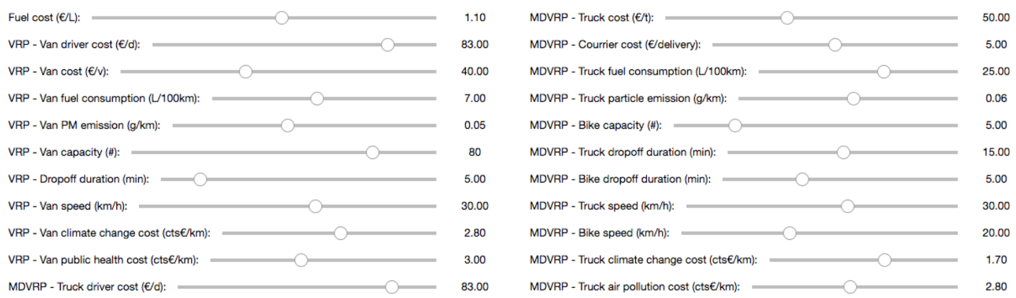

Fig. 3. Parameters of the interactive simulation

```
+-----------------------------------+-------+-------+
|               Output              |  VRP  | 2EVRP |
+-----------------------------------+-------+-------+
|          Number of drivers        |  3.0  |   1   |
|         Number of courriers       |   0   |  42.0 |
|  Total distance with vehicles (km) | 114.5 | 29.47 |
+-----------------------------------+-------+-------+
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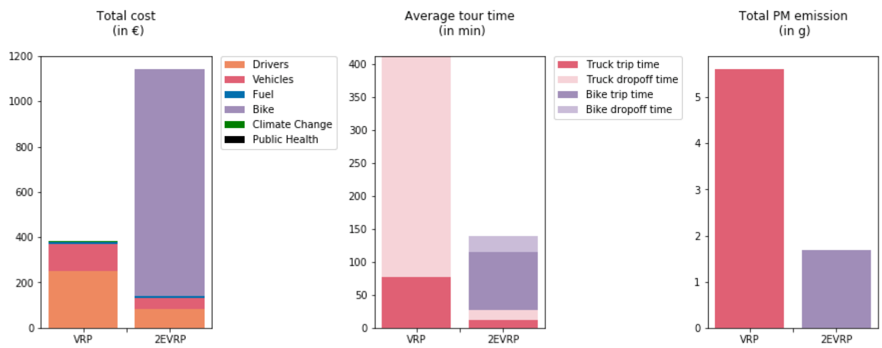

Fig. 4 Outputs of the interactive simulator for a chosen set of parameters

The jupyter notebooks can also take advantage of the “binder” online service. The notebook is available for anyone to test from a web browser. A significant advantage of using jupyter notebooks relies on the fact that they are run on a remote server; as a result, there is no need for local environment configurations by the users. The interactive simulator used in this paper can be accessed at the following link: https://github.com/arthurgaudron/interactive_sim.

3. Results and discussion

3.1. Expected feedback

Two comprehension levels of the models have been considered. The first level is the identification of the parameters and their relationships. From this perspective, the user uncovers the basic foundations of the model. The second level is the identification of possible inconsistencies in the model. The user acknowledges the limitations of the tool and can ponder the conclusions drawn from it.

In the first level, users should identify the relationships between parameters:

- Capacity, number of vehicles and distance: vehicles with lower capacity will induce more travels in order to satisfy the same demand. As a result, there are more vehicles and total distance is increased.
- Lead-time and cost: more vehicles will lower the delivery lead-time but increase the cost.
- Some parameters (e.g. external costs) have limited impact on the total cost.

In the second level, users should be able to criticize the model with arguments:

- Understand that parameters should have an influence on each other. For example, fuel consumption and particle emissions, speed and fuel consumption, price of delivery and increase of capacity, public health cost depends also on the PM emission of the motorization.
- Identify missing parameters: choice of hubs’ localization, information system cost, transshipment cost.
- Assess the limits of the chosen parameters. For example, average speed can be used to represent fluidity of the traffic. However, this may be an oversimplication of the traffic phenomena.

Table 3. Questions and scores from the experiment on 28 students. The answers in the first part were True/False (T/F) or redacted (R). In the second part, users had to choose a value between 1 (strongly disagree with the statement) to 5 (strongly agree with the statement).

	Questions	Score (%)	Level
Understanding of the models and the problem	In real life, the capacity of the vehicles impacts the size of the fleet. (T/F)	100%	1
	In the VRP simulation, the capacity of the vehicles impacts the size of the fleet. (T/F)	79%	1
	In the 2EVRP simulation, the capacity of the bikes impacts the cost. (T/F)	76%	1
	Why 2EVRP is more expensive than VRP? What do you think is missing in the model? (R)	26%	2
	What would be the main parameter to change to make the VRP as fast as the 2EVRP? (R)	76%	1
	Identify two independent parameters in the simulation that are dependent in real life. (T/F)	66%	1
	Identify two missing parameters. (R)	60%	2
	Identify the limitation of one parameter. Why is it not representing the reality accurately? (R)	28%	2
	Identify two parameters with a limited impact in decision. (R)	43%	2
	Delivering a parcel with a bike costs in average 5€. How could companies decrease their average price? (R)	14%	2
Feedback about the tool	You figured out the tool’s limitations, although it is a useful tool for communication. (1 – 5)	70%	N/A
	You feel confident to explain the model and its limits to a client. (1 – 5)	66%	N/A
	Interactivity helped you to explore the model and its limits. (1 – 5)	80%	N/A
	Would you consider the tool to teach someone about VRP and 2EVRP? (1 – 5)	72%	N/A
	Do you think other tools/solutions might have been more suitable? (1 – 5)	N/A	N/A
	Any comment? (R)	N/A	N/A

In the trial performed for this research, self-evaluation and direct observation were used in order to test the understanding of the users. For the self-evaluation a survey was performed. The direct observation is performed with a supervision of the trial. The expert is supervising the experiment, asks and answers questions, and follows the progress of the users. Table 3 presents the questions and the results of the survey. The survey was developed in a brain storming session after identification of the key components of these distribution problems. The score indicates the average accuracy of the answers.

3.2. Feedback from the trial

The interactive simulation tool was tested with 28 participants from 11 different nationalities. They all had an engineering background with diverse specializations: architecture, civil engineering, technology management, electronics, mechanical engineering. The trial took place in the middle of a week dedicated to urban logistics, as a result the students were fairly aware of the relative problematics.

The participants had 45 minutes to test the interactive simulator. They were guided by the questionnaire shown in Table 3, which intended to test their understanding of the model. Results were not *graded*, so it is considered a sincere feedback. However, results have to be considered cautiously as validation test of the survey has not been carried out due to time constraint.

The objective was to test the capacity of participants to understand the two proposed models. To this end, minimal information was given at the beginning. More information was given to everyone upon request. The correctness of their answers is difficult to evaluate as nobody can claim to know the truth. Redundant questions in the survey show the absence of contradiction in the users' reasoning. The questions and scores are displayed in the Table 3. The first ten questions aimed at assessing the comprehension of the models. The last six questions aimed at obtaining feedback about the tool and the opportunity for using it as a communication support.

First, the results are encouraging. Most of the users got involved in the exercise. Although they were not deeply familiar with the urban logistics issues, they were able to tackle most of the questions in a short time.

Second, there is a clear difference of performance between the level 1 and level 2 questions. Users had lower performance on the questions relative to the limits of the tool (level 2). There is a great disparity in the results. Direct discussion during the test showed that some participants were quick at finding flaws in the model. On the contrary, some users seemed to be confused with the concept of model, and the fact they would have to study a *wrong* model. This confusion may have affected the quality of their answers.

Third, the answers and discussions showed that the inexperience about optimization and the lack of information prevented the users to fully apprehend the proposed models.

4. Conclusion

This paper proposed a tool that explored two distribution schemes using interactive simulation. The tool was tested on a trial group of 28 participants that did not know these schemes beforehand.

The results of the trial highlight that interactivity helps users to understand the models and their limits. It showed that users were able to get familiar with a new problem through the use of interactive simulation. Users can easily identify what are the significant parameters (or combinations) impacting the KPI. Users can also imagine their own hypothesis, and check if the model took them into account. They have appreciated the possibility of changing parameters. The fast response from this simulation was an important feature for users.

The assessment of the tool's performance is an important perspective for comparison with other learning material. As this tool has a teaching purpose, we considered the understanding of the participants as an evaluation metric. However, there are many methods to test the understanding of a subject: self-evaluation, one-to-one interview, dissertation, etc. As a first step, it would be valuable to test two different groups (e.g. interactive simulator vs. text book) with different evaluations (e.g. self-evaluation vs. one-to-one interview). It also opens the question of the complexity the model used: how to measure complexity? what is the maximum complexity one can use with an interactive simulator?

In urban logistics, interactive simulation can be a dissemination tool to involve non-experts in the decision process. Once the public is involved, they can give their opinion on the choices made in their city. One fundamental difficulty in city logistics is the multiplicity of objectives. A promising opportunity for interactive simulation is that it could be used to consult people on their priorities and to find out how they perceive choices of others, more precisely it could be used to validate regulations, new logistics schemes and offers.

In addition, being a dissemination tool, the proposed interactive simulator can be used as a support for animating discussions between several stakeholders. From the expert point of view, animating a discussion through interactive simulation allows three main advantages: (1) integrating the opinions of actors with different backgrounds; (2) identifying the main priorities of the participants (what KPI are relevant for which actors); (3) converging to a configuration of parameters that embodies an acceptable trade-off.

As a conclusion, the global feedback supports the perspective to consider further the interactive simulator. The proposed tool has shown its capacity to involve users in the learning process. The accessibility of this type of tool is questionable for a model with a higher level of details. As the model becomes more and more complex, interaction between the parameters will be harder to track for a non-expert.

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References

Abel, H., Karrer, R., Rapp Trans AG, 2006. Best Practice Handbook (Year 2006); Theme 3: Control and Enforcement in Urban Freight Transport; Theme 4: City Access Restriction Schemes. Best Pract. Handb.

Best, B., 2005. A model of fast human performance on a computationally hard problem. Proc. 27th Annu. Conf. Cogn. Sci. Soc. 256–261.

CE Delft, 2016. STREAM Freight transport 2016 - Emissions of freight transport modes.

Comi, A., Rosati, L., 2015. CLASS: A DSS for the analysis and the simulation of urban freight systems. Transp. Res. Procedia 5, 132–144. https://doi.org/10.1016/j.trpro.2015.01.007

Crainic, T.G., Perboli, G., Mancini, S., Tadei, R., 2010. Two-Echelon Vehicle Routing Problem: A satellite location analysis. Procedia - Soc. Behav. Sci. 2, 5944–5955. https://doi.org/10.1016/j.sbspro.2010.04.009

Dablanc, L., 2007. Goods transport in large European cities : Difficult to organize , difficult to modernize 41, 280–285. https://doi.org/10.1016/j.tra.2006.05.005

Debrie, J., Heitz, A., 2017. La question logistique dans l'aménagement de l'Ile-de-France : formulation d'un enjeu métropolitain versus absence de concrétisation dans les projets urbains ? Géographie, économie, société 19, 55–73. https://doi.org/10.3166/ges.19.2017.0003

Drexl, M., Schneider, M., 2015. A survey of variants and extensions of the location-routing problem. Eur. J. Oper. Res. 241, 283–308. https://doi.org/10.1016/j.ejor.2014.08.030

European Commission, 2011. COMMUNICATION FROM THE COMMISION: A Roadmap for moving to a competitive low carbon economy in 2050. COM(2011) 112 Final 34, 1–34. https://doi.org/10.1002/jsc.572

Gabriel, T., Laporte, G., 1997. Planning models for freight transportation 0.

Gonzalez-feliu, J., Perboli, G., Tadei, R., Vigo, D., 2008. The two-echelon capacitated vehicle routing problem To cite this version : The Two-Echelon Capacitated Vehicle Routing Problem. <Halshs-00879447>.

Grzybowska, H., Barceló, J., 2012. Decision Support System for Real-Time Urban Freight Management. Procedia - Soc. Behav. Sci. 39, 712–725. https://doi.org/10.1016/j.sbspro.2012.03.142

Kawrykow, A., Roumanis, G., Kam, A., Kwak, D., Leung, C., Wu, C., Zarour, E., Sarmenta, L., Blanchette, M., Waldispühl, J., 2012. Phylo: A citizen science approach for improving multiple sequence alignment. PLoS One 7. https://doi.org/10.1371/journal.pone.0031362

Korzhenevych, A., Dehnen, N., Bröcker, J., Holtkamp, M., Meier, H., Gibson, G., Varna, A., Cox, V., 2014. Update of the Handbook on External Costs of Transport. Final Rep. 139. https://doi.org/Ref: ED 57769 - Issue Number 1

Perboli, G., Rosano, M., Gobbato, L., 2015. Decision support system for collaborative freight transportation management : a tool for mixing traditional and green logistics . 6th Internaationall Conf. Syst. Logist. Sulpply Chain 2–9.

United Nations, 2014. World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352), New York, United. https://doi.org/10.4054/DemRes.2005.12.9

Vogel, J.J., Vogel, D.S., Cannon-Bowers, J., Bowers, C.A., Muse, K., Wright, M., 2006. Computer Gaming and Interactive Simulations for Learning: A Meta-Analysis. J. Educ. Comput. Res. 34, 229–243.